Distribution and relative abundance of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean

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The blue shark, *Prionace glauca*, is one of the most abundant oceanic-epipelagic sharks and is probably the widest ranging chondrichthyian (Compagno, 1984). It is frequently caught by tuna longline fisheries in temperate, subtropical, and tropical waters of the world oceans (Pratt, 1979).

Hazin et al. (1990) investigated the distribution and abundance of pelagic sharks caught from 1983 until 1988 by Brazilian longliners in the southwestern equatorial Atlantic. Blue shark and sharks of the genus *Carcharhinus* were the dominant species, together representing nearly 95% of the shark catches (Hazin et al., 1990). They reported that blue shark abundance had a marked seasonal fluctuation with the highest catches taking place during the third and fourth quarters of the year and the lowest in the first quarter.

The objective of the present study is to further investigate the distribution and relative abundance of the blue shark, *Prionace glauca*, in the south-western equatorial Atlantic Ocean, including the following aspects: a) seasonal fluctuation of catch per unit of effort (CPUE) as related to sea surface temperature; b) sex, and size and age composition of blue shark catches; c) vertical distribution as related to the vertical temperature profile.

Material and methods

This study was based on shark catches during 50 fishing cruises by a commercial tuna longliner, FV *Argus*, from August to December 1987 and from February 1990 to December 1991. On 325 longline operations during these cruises, a total of 992 blue sharks were caught. The commercial longline consisted of 120 baskets, each with 7 branch lines. The bait was frozen Brazilian sardine, *Sardinella brasiliensis*. Average local time of set, retrieval, and mean soaking time of the longline is shown in Table 1. Further details of longline fishing gear and methods were described in Hazin (1986).

The fishing ground was located between lat. 2°S and 7°S and long. 32°W and 38°W. Fishing areas were divided into segments of 1° latitude × 1° longitude. The central positions of the 325 longline sets (Fig. 1) were calculated as the average latitude and longitude of the beginning and end of set and retrieval. Distribution of fishing effort by month is presented in Table 2. Blue shark relative abundance was expressed as average catch, in number of fish, per 100 hooks (CPUE). The mean CPUE was calculated as the total catch, in number of fish, divided by the total fishing effort, in 100 hooks. The distribution of blue shark mean CPUE by segments of 1° latitude × 1° longitude was observed and its relation to ocean depth analyzed. Ocean depths for each longline set were calculated as the weighted mean of the three closest values read from the nautical chart number 50, issued by the Brazilian Navy.

The monthly fluctuation of CPUE and sex ratio was analyzed and compared to sea surface temperature. An analysis of variance

(ANOVA) was performed to determine whether blue shark CPUEs were significantly different among months. The mean CPUE for each month was calculated and all monthly mean CPUEs were then compared by ANOVA, through one-way classification of data. The months were the only independent variable (Table 3). No CPUE data were available from October 1990 and from January and April 1991. Data on the sex of the specimens were not available from January to October 1991.

All lengths are reported as fork length (FL), which was measured from the tip of the snout to the fork of the tail. Blue sharks were always measured at the time of landing. Length data were available only for 1990 and 1991. To better understand seasonal variation in CPUE, CPUE data for the various age classes of male specimens from February through December 1990 were evaluated. Females were not included because they were present only from February to July. To calculate the age-CPUE distribution, male blue shark lengths were converted to age by Stevens' (1975) growth equation, as follows:

$$Lt = 423 \ (1-e^{-0.11(t+1.035)})$$

Table 1

Average set, retrieval and soaking time (in decimals) with standard deviations, for longline operations of FV *Argus* from February to December 1990.

		Local time	Standard deviation
Set	Beginning	1.61	0.58
	End	4.00	0.53
Retrieval	Beginning	10.31	1.47
	End	17.52	1.68
Soaking time (hours)		11.11	1.54

Figure 1

Location of the fishing ground (hatched area) and central positions of the longline sets made by the FV *Argus* from August to December 1987 and from February 1990 to December 1991, in the southwestern equatorial Atlantic Ocean.
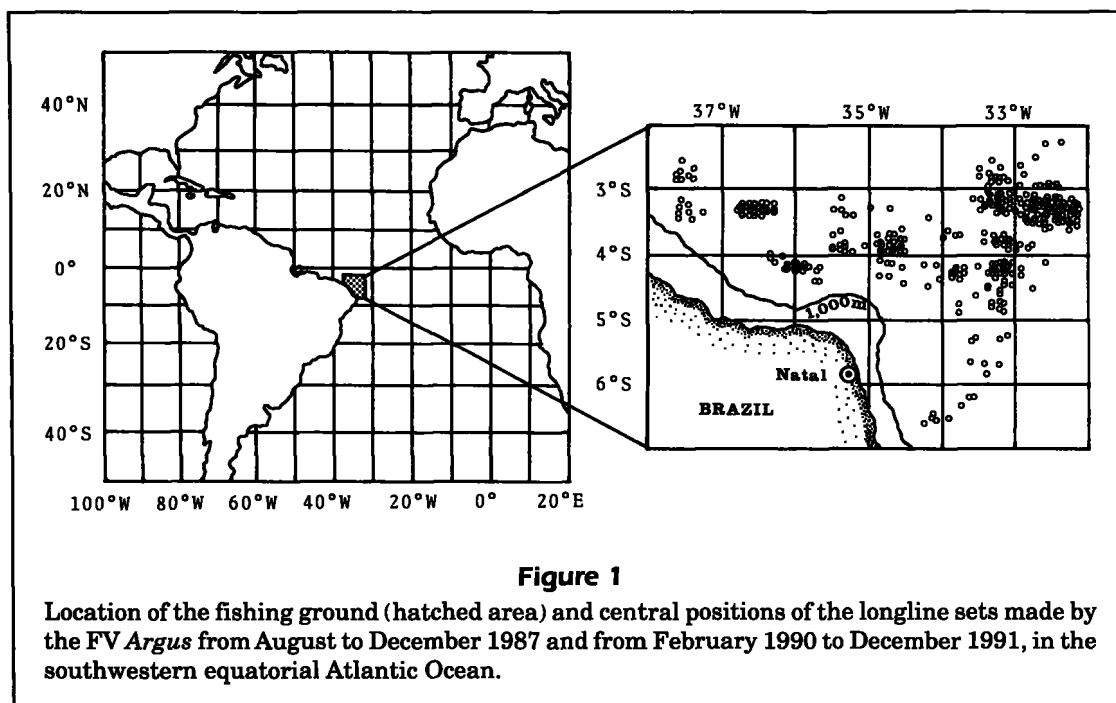
Table 2

Distribution of fishing effort of FV *Argus* by months, from August to December 1987 and from February 1990 to December 1991, in the southwestern equatorial Atlantic Ocean.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
No. of sets	16	12	23	15	27	24	23	32	36	44	39	34	325
%	5	4	7	5	8	7	7	10	11	13	12	11	100

where Lt = total length, and t = age in years. Fork length data were converted to total length by the regression of Hazin et al. (1991):

$$FL = 11.27 + 0.78\ TL$$

where FL = fork length, and TL = total length.

Depths of longline hooks were estimated using the equations of Yoshihara (1952, 1954, a and b). Vertical distribution of males and females was studied through the relative distribution of mean catches on longline hooks, during February to June and July to December 1990. Differences in mean catch of males and females on longline hooks were evaluated by chi-square analysis (df=6). Sea water temperature from 0 to 300 m was surveyed in 35 DBT (digital bathythermograph) profiles: 6 in May 1990, 3 in May 1991, 5 in June 1991, 13 in November 1990, 2 in November 1991, and 6 in December 1990. From January to December 1990, sea surface temperature was measured by a mercury thermometer.

Results

From August to December 1987 and from February 1990 to December 1991, the blue shark mean CPUE by quadrates increased eastward, being particularly high east of long. 35°W (Fig. 2). Of the 325 sets, 260 (nearly 80%) were over bottom depths greater than 1,000 m. In these areas, the mean CPUE of blue shark was 0.50. The remaining 65 sets were in areas with depths shallower than 1,000 m, close to oceanic banks (Aracati, Sirius, and Guara banks), and west of 35°W. In these areas, the mean CPUE of blue shark was only 0.05.

The fluctuation of the monthly mean CPUE of blue shark in the area east of 35°W, over ocean depth of 1,000 m, for 1987, 1990 and 1991, were similar (Fig. 3). In 1990 and 1991 the CPUE was low until May, increased during June and July, decreased again in August, increased during September and October, and decreased once more in November and December. In 1987 the CPUE was low in August, increased in October and decreased during November and December. Differences in mean CPUE among months were significant (ANOVA; $P<0.0001$; Table 3).

The fluctuation of the monthly mean CPUE of male and female blue sharks was distinct (Fig. 4). CPUE for females was highest during March. From July to December, CPUE for females was low in this fishing ground. CPUE for males, however, was lowest during March, after which abundance increased and peaked during September and October. The sea surface temperature in 1990 was highest in May and lowest in September. During this year, in general, the CPUE of males tended to decrease with an increase in the sea surface temperature, whereas the CPUE of females tended to increase.
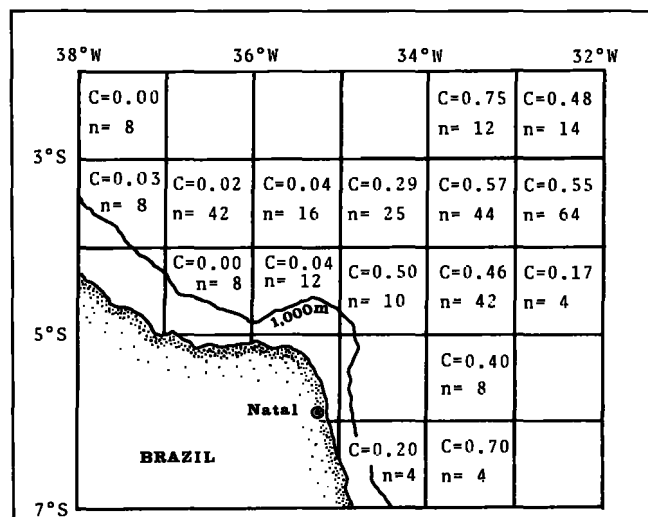

Figure 2

Mean catch per 100 hooks (CPUE) of blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean, from August to December 1987 and from February 1990 to December 1991. C= CPUE; n= number of longline sets.
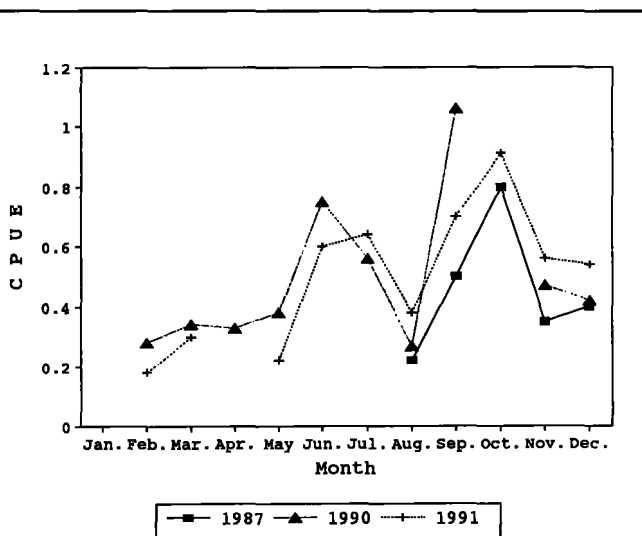

Figure 3

Monthly mean catch per 100 hooks (CPUE) of blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean, in the area east of long. 35°W and with ocean depth over 1,000 m, from August to December 1987 and from February 1990 to December 1991.

Of 810 specimens, 652 (about 80%) were male and 158 were female (about 20%). Overall, the sex ratio (male/female) for the entire period was 4.12:1. The sex ratios for each month are given in Table 4.

Females ranged in size from 162 to 226 cm and males from 156 to 250 cm (Fig. 5). Seasonal fluctuation in male CPUE during 1990 was different among age groups (Fig. 6). From February to May, ages ranged from 4.5 to 8.5 years, with most (83%) individuals between 6 and 8.5 years old (83%). The CPUE rise in June–July was due to an increase in the same age classes as from February–May. Some older specimens from 9 to 10.5 years also appeared. The CPUE of fish younger than 7 years decreased markedly in August. During September–October the CPUE of ages 7.5 to 10 increased sharply. In November–December the CPUE of age classes from 7.5 to 8.5, and also 9.5, were reduced, whereas the CPUE of other age classes did not change much. From February to July, younger fish (4.5 to 7.5 years) were more abundant than from August to December, their CPUE being particularly high in June–July. From August to December, fish older than 7.5 years had a higher CPUE than in the previous months, with a peak in September–October.

The calculated depth of longline hooks during 137 longline fishing operations of 1990 ranged from 87 to 206 m (Table 5). The figures given in this table approximate the actual depths of longline hooks. The most striking feature of the DBT profiles is the pres-

Table 3

Analysis of variance (ANOVA) and expected mean squares for comparison of monthly mean CPUEs of blue sharks, *Prionace glauca*, caught by the FV *Argus*, during 325 longline sets, from August to December 1987 and from February 1990 to December 1991, in the southwestern equatorial Atlantic Ocean.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F	P
Month	24	11.41	0.48	4.65	<0.0001
Error	300	30.68	0.10	—	—
Total	324	42.09	—	—	—

n= 104

n= 374

Figure 4

Monthly mean sea surface temperature in 1990 and monthly mean catch per 100 hooks (CPUE) of male and female blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean, from August to December 1987 and from February 1990 to December 1991.
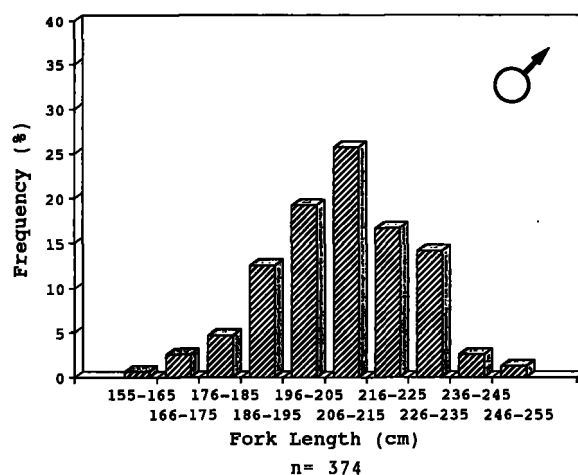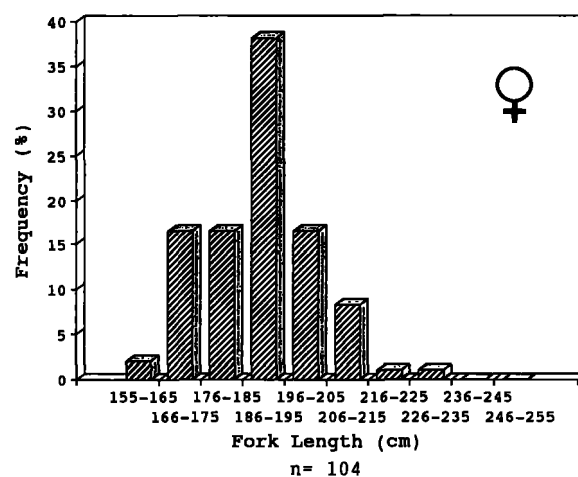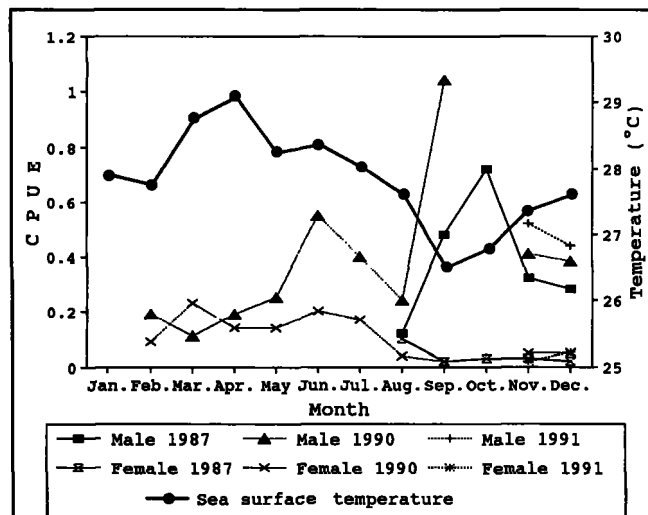
Figure 5

Length-frequency distribution of male and female blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean, from February to December 1990 and November to December 1991. Males: n = 374; min. = 156 cm; max. = 250 cm. Females: n = 104; min. = 162 cm; max. = 226 cm.

ence of a steep thermocline during the entire year. The range and mean of sea water temperature at the calculated depths of longline hooks, and the mean depth and temperature at the top and bottom of the thermocline in May–June and November–December are shown in Table 6. All longline hooks were located in or below the thermocline (Fig. 7). During Nov.–Dec. the thermocline was about 30 m deeper than during May–June.

Male blue shark catches from February to June were concentrated among central, deeper hooks, whereas in the second half of the year they were more uniformly distributed (Fig. 8). Male catch was significantly different among hooks from February to June (chi-square; $P<0.005$), but not from July to December ($0.10 < P<0.25$). The difference of male catches, on hooks 3, 4, and 5 between February-June and July-December was significant ($0.05 < P<0.10$). The relative distribution of female blue shark catches along longline hooks from February to July (Fig. 8) was different from that of males; the highest catches took place on hooks 2 and 5. The difference between male and female catches among hooks during February to July was significant ($0.01 < P<0.05$). The distribution of male and female catch among hooks suggests that males were distributed in shallower waters between July and December than between February and June and that females from February to July had a shallower distribution than males.

From February to July, CPUE for females was highest in hooks 2 and 5 (130 to 165 m), and CPUE

for males in hooks 3 and 4 (165 to 180 m) (Table 5). The corresponding range of sea water temperature was 13.8° to 20.4°C for females and 12.9° to 17.1°C for males (Table 6). Male catch among hooks from July to December, was much more uniform, suggesting a depth range for males from 90 to 180 m (Table 5), or from about 15° to 28°C (Table 6), up to the top of the thermocline (Fig. 7).

Discussion

The results on horizontal distribution agree with those of Hazin et al. (1990), corroborating the oceanic character of blue shark (Fig. 2). Abundance was also clearly related to bottom depth. The mean CPUE of blue shark in areas of bottom depths greater than 1,000 m was 10 times higher than in shallower areas. The lower abundance of blue sharks west of 35°W

Table 4

Blue shark, *Prionace glauca*, monthly sex ratio (number of males per female), in the southwestern equatorial Atlantic Ocean.

Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2.08	0.48	1.29	1.79	2.71	2.35	6.00	54.00	25.00	16.00	8.50

Table 5

Mean and range of calculated depths (m) of longline hooks, during 137 longline operations, in the southwestern equatorial Atlantic Ocean, from February to December 1990.

Hook no.	Mean depth	Minimum	Maximum
1 and 7	92.66	87	96
2 and 6	131.56	120	140
3 and 5	164.19	145	181
4	179.20	154	206

Table 6

Range and mean of sea water temperature (°C) at calculated depths (m) of longline hooks 1 to 7 and mean depth and temperature at the top and bottom of the thermocline, as inferred from 35 DBT (digital bathythermograph) surveys carried out in May–June and November–December 1990 and 1991, in the southwestern equatorial Atlantic Ocean.

| Month | Hook number | | | | Thermocline | | | |
| | | | | | Top | | Bottom | |
	1 and 7	2 and 6	3 and 5	4	Depth.	Temp.	Depth.	Temp.
May–June								
Temp. mean	22.6	16.3	14.8	13.2	55	28	120	13.5
Temp. range	18.5–25.7	13.8–20.4	13.1–17.1	12.9–13.3				
Nov.–Dec.								
Mean	27.6	17.0	15.4	14.9	85	27	130	15.5
Range	26.8–29.1	14.3–24.0	14.0–20.1	13.9–18.6				

(Fig. 2), therefore, is probably a consequence of ocean depth, because almost all sets performed in this fishing ground took place in shallow depths and in the vicinity of oceanic banks.

The monthly mean CPUEs of males and females (Fig. 4) show that the higher relative abundance of blue shark during the third and fourth quarters of the year (Hazin et al., 1990) is mostly comprised by males. These results indicate also that males and females are segregated and that their migratory movements are different. The different seasonal fluctuation of CPUE for different male age groups indicate that male specimens were also segregated by size. The use of Stevens' (1975) growth equation to calculate these ages from fork length may have limitations because it is based on data from the North Atlantic Ocean. Nevertheless, Amorim (1992) studied the growth of blue shark in the south-western Atlantic and found a value of k= 0.1126, which approximates Stevens' value of 0.11.

Differences in vertical distribution displayed by male and female blue sharks (Fig. 8) indicate that vertical sexual segregation likely occurred in the first half of the year. They also suggest that the depth range of male blue sharks may change seasonally.

Acknowledgments

Figure 7

Typical temperature profiles for May and November, in the southwestern equatorial Atlantic Ocean, and the calculated mean depths of the hooks 1 to 7 of the longline of the FV *Argus*.
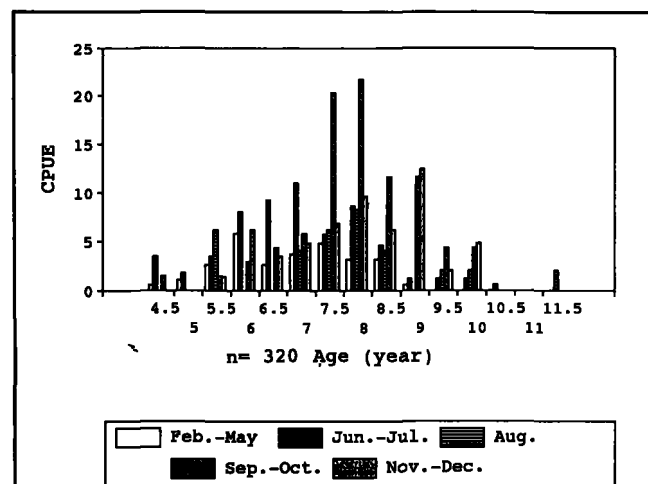

Figure 6

Mean catch per 10,000 hooks of male blue shark, *Prionace glauca*, by age classes, from February through December 1990, in the southwestern equatorial Atlantic Ocean. n = 320.
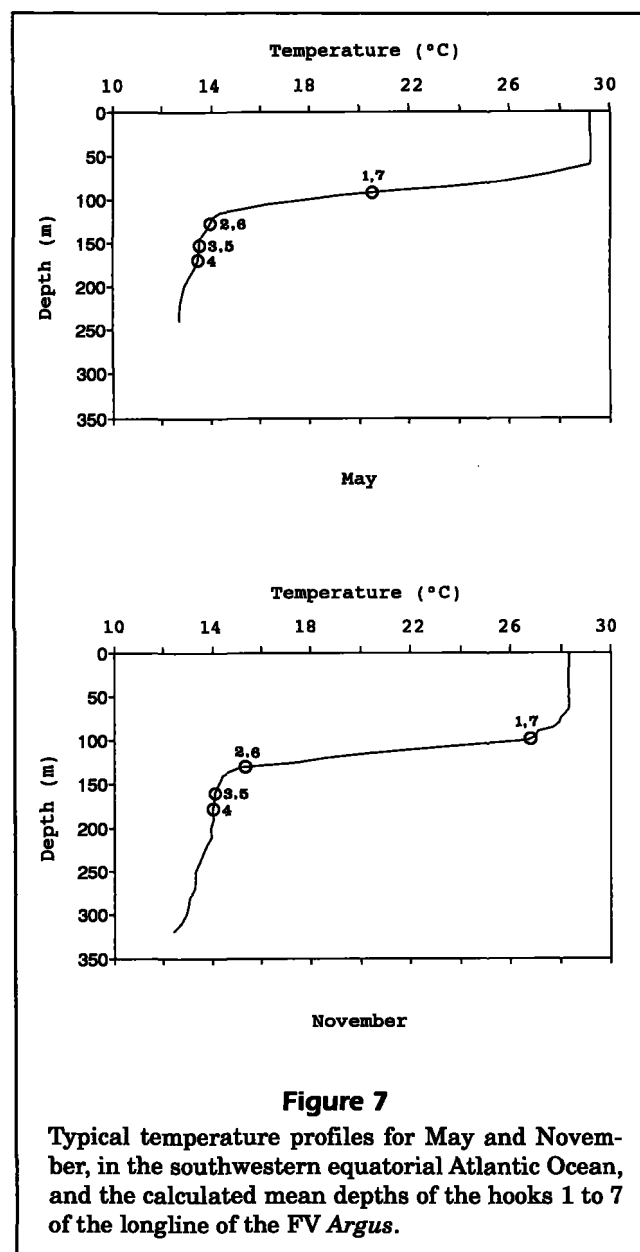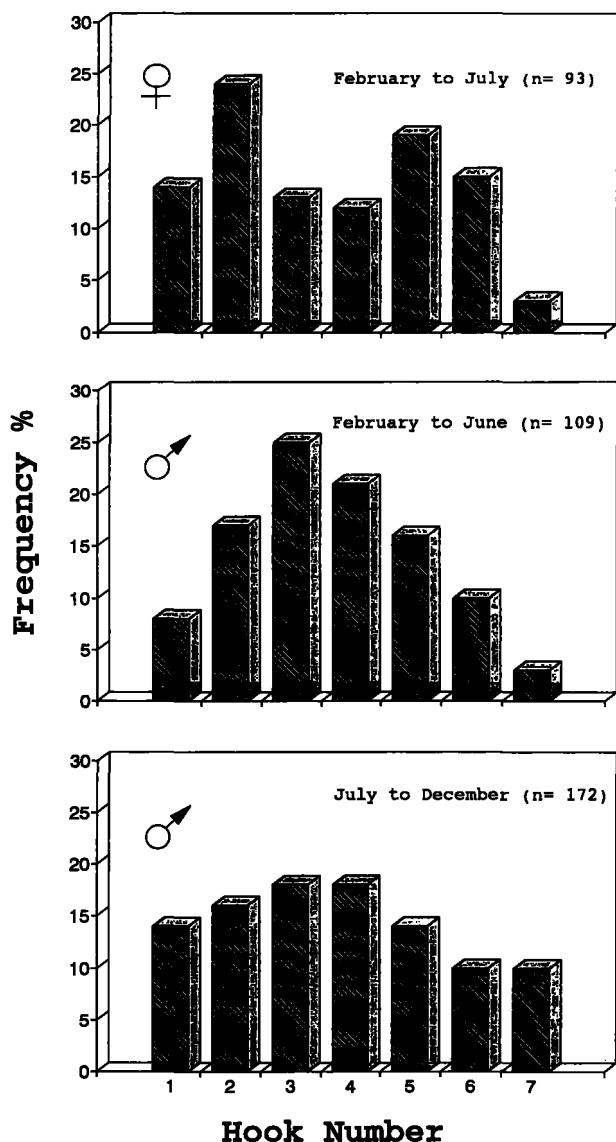
Figure 8

Male and female blue shark, *Prionace glauca*, catch-frequency distribution along the hooks of the longline, in the southwestern equatorial Atlantic Ocean, during February to June and July to December, 1990.

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